Effect of Six-Week Hang Clean Training on Underwater Push-off Velocity

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LIST OF ABBREVIATIONS

Underwater push off……………………………………………………………..UW push off

Hang Clean…………………………………………………………………………….HC

Non Hang Clean……………………………………………………………………....NHC

Weight Training ……...………………………………………………………………..WT

Control group………………………………………………………………………....CON

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ABSTRACT

Strength and conditioning training is seen to have a direct correlation in improving power, strength and speed in sports. This study investigates the effects of the Olympic weightlift, hang cleans (HC), on the velocity of an underwater (UW) push off in the sport of swimming. Twenty-five college students enrolled in a beginner swimming class were randomly assigned to a weight training (WT) (n=15) or control (CON) (n=10) group. Each group practiced twice a week for six weeks during their regularly scheduled swimming class. Subjects who were part of the WT group followed a HC regime at the beginning of each swim class and afterwards joined the swim class. The CON group continued their normally scheduled swim class. Each subject's UW push off velocity was recorded and analyzed at the beginning and end of the study. Neither groups UW push off velocity improve significantly enough to say that the hang clean training benefited their velocity. This could be due to multiple factors such as sample size, speculating practicing technique over cross training to be more beneficial and hang cleans not being the best exercise to improve a beginner level swimmer's swimming ability. More research is needed to confirm the effects of hang cleans on UW push off velocity and other aspects of swimming but future research should take into consideration the different swimming levels of the participants.

Key words: Hang cleans, underwater push off, velocity, swimming, cross-training, strength and conditioning

INTRODUCTION

Factors such as strength, power and endurance for long term training is important to develop at an early stage (Hiro, 2008). Competitive swimming is a known world-wide sport that demands land cross training along with training in the water (Bishop, 2013). When taking a closer look at high performance swimmers, more often than not, they pair their swimming training with strength and conditioning training outside of the water. This training develops the previously mentioned factors, strength, power and endurance, to then translate those developed qualities to the water. Furthermore, swimming is a sport that demands a great amount of explosive movements at the start and off the push offs (Oranchuk, 2019). More recent research suggests that by incorporating a strength and conditioning training program, it will have some of the greatest immediate impact on a athlete's swimming (Bishop, 2013).

Common strength and conditioning practice includes the incorporation of Olympic weight lifting exercises. A hang clean (HC) a well-known Olympic lift, is a exercise used throughout many sports and weight training programs to develop athlete's strength and power including swimming. The HC itself is a combination of upward movements of the bar in one continuous motion beginning at the mid thigh. This "rapid acceleration extended through the entire movement" develops an athlete's power output and therefore develops one's overall velocity (Haff, 2012). For land based sports, it has been seen as a tool to improve sprinting, change of direction and jumping (Haff, 2012).

Swimming in itself is an activity made up of many movements which utilize and develop many different physical attributes (Crowley, 2017). One of the movements in swimming that requires explosive actions is a push off the wall. This is commonly known as the underwater push off. In this motion, a swimmer is completely submerged underneath the surface of the water and pushes off the wall horizontally with their feet moving them towards the other side of the pool. This is a movement that is used in the sport of competitive swimming to start a swim lap or the change direction in swimming.

There lacks more concise research in literature on which specific strength and conditioning exercises correlate to distinct strokes or movements in the sport of competitive swimming and swimming in general. The majority of literature focuses on the effects that strength and conditioning has on land sports but lacks research for water based sports. Furthermore, swimming related research is centered around the biomechanics of the individual strokes. Because there is a lack of research on strength and conditioning and its effects on swimming, more research needs to be conducted to see the outcomes and reasoning behind incorporating it into training for swimmers.

Therefore, it is theorized that by incorporating the exercise of the HCs in swimmers training regime, no matter their level of swimming, it will help their swimming by focusing on developing strength and power to then be translated into the velocity of a underwater push off. The purpose of this study is to examine the effects of the HC weight training exercise on the underwater push off. It is hypothesized that the group of swimmers that include HCs into their training routine will have a higher increase in their push off velocity in comparison to those who only swim.

METHODOLOGY

Research Design

The purpose of this study was to determine the effect of a swim six week HC weight program on UW push off velocity compared to those who just did a swim program. We hypothesized that those in the swimming and weight group would significantly increase their UW push off velocity after 6 weeks to a greater extent than those in the swim only group. The intervention of the study was the HC training program executed at the beginning of each swimming class (2 times per week) that the experimental group performed. The dependent variable was the resulting UW push off velocity after the 6 weeks for both control and experimental group. All testing procedures was done during class time and as part of the class activity for the Kinesiology and Rehabilitation Sciences swimming classes at the University of Hawaii. This small study could be used as seed data to "inform" a bigger future study, as this is the first study to examine these variables.

Participants

Twenty five students participated in the study which consisted of 15 in the weight training group and 10 in the control group. They were recruited from over 60 students who were enrolled in the spring 2019 semester-long beginner swimming courses offered by the Department of Kinesiology and Rehabilitation Sciences. The sample size was chosen based on previous studies that have been done with “23 subjects during a six-week intervention” (Ayers, 2016). Subjects was randomized into the two groups. The weight program did not take extra outside class time; it was implemented into the first 7-10 minutes of their class time. Each subject voluntarily read and signed a written consent form prior to participation. Only subjects who have signed the consent form were included in the study. Prerequisites for selection of the study was the ability to meet these requirements and perform the following skills:

1. Participants must be 18 years or older

2. Participants must understand and communicate in the English language

3. Lift and comfortably hold for 30 seconds a 45-pound Olympic weight lifting bar with additional 8 pounds attached to the bar (53 pounds total)

    3a. Due to the fact NSCS requires strength training to start at 85% of max. If they can lift 53 pounds, then their 85% would be the 45 – pound Olympic weight lifting bar

4. Completely submerge under the water

5. Have the ability to execute a proper streamline and push off while holding the fully extended body position for 10 seconds UW

6. Have no prior or current injury that could limit movement

7. Must attend primary investigators proper HC technique demonstration and perform a proper HC 3 times

Subjects who did not meet all the qualifications for any reason were not included in the study. The study was approved by the University of Hawaii at Manoa University Institutional Review Board for the Study of Human Subjects.

Site and Preparation

Equipment:

The subject's motion for data collection was recorded using a single Sony video camera (Model a7sii). The film rate was set at 120 frames per second. The camera was secured in an UW housing and mounted to the pool deck via a custom-designed frame. The mount was held in a stable position at the edge of the pool secured by three 25- pound plates. Pre-existing markers have been drilled into the cement of the pool deck on one end of the pool exactly 11 inches from the edge of the width of the pool by 96 inches from the edge of the length of the pool ensuring the camera mount is placed in the same location each time. The camera was attached to the retractable mounting plate and adjusted under water to enable the videotaping of the subject at a distance of 5.2 meters. The distance calibration was conducted using two-yard sticks attached in series and mounted on a frame that was placed on the bottom of the pool directly above the subject. The total measurable distance of 72 inches is result of the two-yard sticks together.

The weight racks are set up with an Olympic style bar with revolving sleeves. Spotter bars were placed on the weight racks for safety purposes. The weight plates were set up readily available to be placed on the bar for the subjects to lift.

Intervention Procedure: Hang Clean Weight Program

The subject's one repetition max was calculated from the amount of weight they were able to properly lift for three repetitions. Then, throughout the program, for six weeks, they started at 85% of that estimated one repetition max and slowly increased if they are able to. Each weight lifted by the subject was recorded to track progress. The program design was the same for each student. They went through the same dynamic warm up targeting muscles used in HC. The warm up consisted of: walking lunges with a torso twist, straight leg high kicks, arm swings forward and backward, and overhead latissimus dorsi stretch. They also did the same amount of HC sets and repetitions. Each student was given a weight increasing each week based off their first HC 3 repetition maximum test. Reference Table 1. A supervised instructor (primary investigator) was present to suggest modifications to weights if the participant could not complete the prescribed weights. After six weeks, the subject's one repetition max was recalculated from the amount of weight they can properly HC for three repetitions to then be compared to their first test at the beginning of the 6 weeks. Table 1 illustrates the program design from the subjects in the experimental group via National Strength and Conditioning Association guidelines (Haff, 2016).

Table 1: Hang Clean Program Outline

Week	Load	Reps	Sets	Rest
0	TEST 3RM			
1	85%	6	3-4	2-5 min
2	85%	6	4-5	2-5 min
3	80% (lighter week)	6-8	3-5	2-5 min
4	90%	4-6	4-6	2-5 min
5	90%	3-6	4-6	2-5min
6	75% (Unload week)	6-8	3	2-5min
7	TEST 3RM			

<u>Intervention Procedure: Swim Program</u>

All beginning swim classes lasted on average 45 minutes throughout the spring 2019 semester. The yards will range anywhere from 500-800 yards per session and focused on the freestyle and backstroke swimming strokes.

<u>Testing Protocol:</u>

Subjects were led through a dynamic warm up with exercises that prepare the major muscles used in the HC exercise. The subjects were then instructed and observed by the researcher on the proper HC technique before testing starts.

Figure 1 provides three photographs of the technique shown at the three stages of the exercise.

Technique checks that the researcher looked for included:

1. The width the feet are planted on the ground relative to the hip
2. During the squat, the bar hanging slightly above the knees
3. Hands were placed on the bar wider than shoulder-width
4. Subjects must hold a neutral body position.

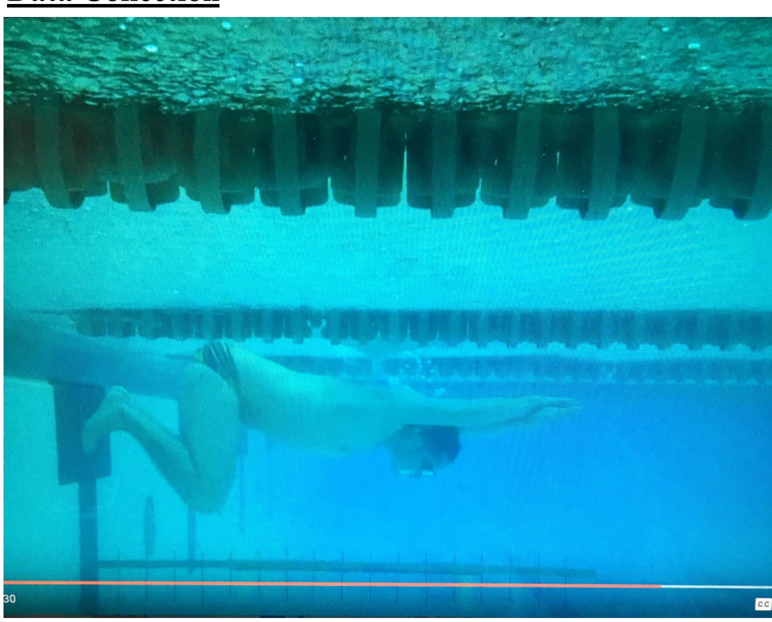
The pull phase of the HC, the bar should be close to the subject's body. In the finishing HC phase, the subject's spine was aligned, and the subject's elbows was elevated. After the subject was capable of demonstrating the required technique of the HC exercise three times, additional weight was then added. The subject's one repetition maximum was calculated from the amount of weight they could perform for a total of three repetitions for the HC exercise. Subjects were tested for their UW push offs (Figure 2). The subject's iliac crest was marked in order to visually indicate the starting point and finishing points of the UW push off as visible in the camera. Subjects were required to practice the movement by demonstrating three successful UW push offs in order to avoid the learning curve bias. The required steps for a successful repetition was the ability to submerge completely under the water, execute a proper streamline, push off, and holding the fully extended body position as determined as a prerequisite earlier. Formal filming and data collection commenced after the subject successfully demonstrated the required underwater motion. Each subject was filmed for a total of five repetitions of the push off. The subject was required to push off the wall in a prone position above the custom built underwater stand while being filmed. Using the information obtained from the calibration frame and camera speed, the velocities of the push off can be calculated. When the camera films the subject, it captured both the distance (inches) from the yard sticks and tracks the time. Both components were used to take the average velocity of the UW push off of each subject. The study period was scheduled to last for six weeks, with the subjects performing the required HC program twice a week during the beginning of their swimming class. Data pertaining to each subject's exercise load was recorded at each session. The same measurement procedure was repeated. This measurement includes testing the three-repetition max in the weight room and the velocity during another session of UW push offs.

Following the testing days, students that were in the WT did their program. Those who were not in the WT started swimming with a warm up that took between 7-10 minutes. The students in the WT joined the swimming class after they have completed the 7 – 10 minutes HC program.

Figure 1: HC Technique - Haff 2016 Essentials of Strength Training and Conditioning

Figure 2: UW Push Off - picture from pilot video

Data Collection



Preliminary subject data will include height, weight, and age. Measurements will be taken from each subject on the first day and last day of the 6-week testing in order to see the difference in UW push off velocity from before and after the HC program. The average velocity was measured by observing the recorded footage for each subject. The subject's squatted starting push off position and their fully extended finishing position was easily indicated by the subject's marked iliac crest in correlation to the yard stick. Subtracting those two points on the yardstick gave the distance the subject travels. The time was also examined by observing the frames per second it took the subject from start to finish. By taking the distance divided by the time, the average velocity was calculated five times for each subject. After those five measurements are taken, the average of those was documented.

Each UW push off trial was captured by the camera and then imported into a video file. The position of the iliac crest at the starting point above the yard sticks and the ending point when the subject was in a full extension position was recorded. The resulting displacement of the iliac crest at the starting point and the ending point when the subject is in the full extension position will be recorded. The resulting displacement of the iliac crest was used to calculate the velocity of each push off. In the weight room, the subject's one repetition maximum was calculated by the amount of weight in pounds they can properly lift from a three-repetition maximum.

Statistical Analysis

A HC program and swimming will significantly improve UW push-off velocity over 6 weeks and to a greater extent than just swimming, we will use a Mixed Method Analysis of Variance (ANOVA). We will examine a main effect for group (experimental and control) a main effect for time (0, 6 weeks), and a group*time interaction. Additionally, we ran a Correlation test on the HC subjects only determining the person product moment correlation coefficients between strength and swimming velocity variables.

RESULTS

Participant demographics can be found in Table 2. Twenty-five participants were measured divided into HC (N=15) and control group (N=10). There was no statistical significance at the p<0.05 determining any difference between the two groups before treatment except in age. Levene's Test of Equality of Variance shows significance therefore, the equal variance is not assumed. An alternative p value (p<.035) was used for age.

Table 2

Participant Demographics

	Age (years)	Height (m)	Weight (kg)	Prev. Ex WT (months)	Prev. Ex UW Push off (months)
WT (N=15)	23.67±4.79*	1.71 ± 0.1	76.82 ± 14.18	7.6±15.9	27.9±38.95
CON (N=10)	20.5 ±2.1	1.69 ± 0.11	67.1 ± 13.65	5.2±9.95	38.4±61.33

Notes: *indicates p<0.05

A independent sample T-Test was conducted to compare the significance level between the control (N=10) and HC groups (N=15) velocity at baseline. Table 3 presents the independent sample T-Test conducted. There was not a significant difference in scores from control (mean=1.44 SD=.21) and HC (mean=1.52 SD=.18). Considering the level of significance (p>.168) was greater than the previously set level (p>0.05) we accept the null hypothesis and report no statistically significant differences between groups.

Table 3

Groups Baseline Velocity	
	Velocity Baseline
WT (n=15)	1.52 ± .18
CON (n=10)	1.44 ± .21
Notes: n= number of participants	

A One-way Mixed Method ANOVA was conducted to compare the effect of HCs on underwater push off between a control group and experimental group. Table 4 presents the One-way Mixed Method ANOVA test administered. There was no significant effect of the impact HCs had on UW push off velocity at $p<.05$ level for the groups [$F(1,1) = 2.43$, $p=.133$]. This indicates there was no interaction effect from Pre to Post among groups ($p=.393$). Taken together, these results suggest that by incorporating HCs to a training regime it does not have a considerable effect on underwater push off velocity.

Table 4		
Group Velocity Comparison Start to Finish		
	PRE Velocity (m/s)	POST Velocity (m/s)
WT (n=15)	1.52 ± .18	1.55 ± .26
CON (n=10)	1.44 ± .21	1.54 ± .29
Notes: N =the number of participants per group; PRE = before the study; POST = after the study		

Table 5		
Resulting Strength and Velocity – Experimental Group		
	Pearson Correlation	Sig. (2-Tailed)
Post HC 3 Rep	.551*	0.033
Velocity POST (m/s)	.551*	0.033
Notes: * Correlation is significant at the 0.05 level (2-tailed).		

Table 5 represents the correlation for the HC group's strength to their UW push off velocity at the end of the six week training program. We used an alpha level of 0.05. With a linear relationship of .551, this indicates the final hang clean three rep max weight was moderately correlated to push off velocity at the the post test swim.

Table 6		
Hang Cleans PRE to POST Weight – Experimental Group		
Subjects	PRE weight (kg)	POST weight (kg)
1	24.94	27.21
3	70.30	92.97
7	24.94	34.01
8	43.09	61.22
13	24.94	31.75

16	52.16	61.22
17	52.16	63.49
20	34.01	40.82
23	43.09	45.35
26	36.28	49.89
28	61.23	70.29
30	24.94	29.48
33	38.55	52.15
36	52.16	61.22
37	83.91	92.97
Notes: PRE = before the study; POST = after the study		

Table 6 represents the experimental groups three repetition max weight lifted at the start and finish of the six-week training. Each individual participating in the HC training program increased their three-repetition max weight.

Table 7		
Change in Hang Clean – Experimental Group		
	Mean Weight (kg)	Sig
WT (n=15)	9.82±5.53*	0.01

Notes: *indicates $p<0.05$; n= number of participants

Table 7 shows that the paired sample T-Test indicated the hang cleans over time were statistically significant ($p<0.05$). It can be said that the six-week HC strength and conditioning training does improve the subject's HC max.

DISCUSSION

The main finding of this study was when the incorporation of HCs was added to a swimming regime, the underwater push off velocity did not significantly change. We cannot say that there was a strong enough correlation between HC and the UW push offs. Researchers saw that there was statistical significance in the WT group's hang clean training emphasizing that the strength and conditioning training did help improve the subjects hang cleans. However, this development did not translate to the water. Neither groups UW push off velocity saw any significant difference from the beginning to end the of the study.

The current study hypothesized that by incorporating the power exercise HCs in a swimmers training regime, no matter the participant's level of swimming ability, would help their performance by focusing on developing strength and power. That refined strength and power could then be translated into the velocity of a UW push off. From start to finish, the WT group means were $1.52 \pm .18$ to $1.55 \pm .26$ and the CON group means were $1.44 \pm .21$ to $1.54 \pm .29$. This shows the subject's results were not significantly different. We also see that the CON group had a higher increase in their UW push off velocity means over the WT group. This is predicted by researchers to be because of the level of swimming ability. The subjects in the study were all a part of a beginner level swimming class and ranged from no experience to twelve years of experience. It is speculated that they could benefit the most from practicing UW push offs over the incorporation of the HC strength and conditioning training. Theoretically, those with multiple years of experience would have a different effect from the HC or the swimming training than those who had little to no experience.

Competitive swimming is a sport that relies heavily on time. Sometimes races in the sport of competitive swimming can come down to a tenth or hundredth of a second, in which case, a small increase of velocity could be helpful. Considering the majority of participants in this study came from a non-swimming background, the HCs did not make a huge effect on their abilities. It can be speculated that the level of ability of the subjects plays a more significant role in determining which approach would be best to help them develop swimming movements such as the UW push off. Focusing on the techniques of a swimming movement could see better results over incorporating cross training exercises for beginner level swimmers. The results might have been different if the participants were students in an advanced swimming class or even part of the competitive swimming team because these athletes would be closer to having their swimming technique at peak perfection. In which case, the development of strength and power could help for swimming performance. However, because the participants in the study were beginning level, we did not see the significant change we were expecting.

Previous research finds that the incorporation of a weight training regime does improve sport-like performance in athletes (Haff, 2012). The WT method in this study was similar to Ayers et. al.2016 who also observed the HC and additionally observed the hang snatch. Researchers in that study found a significant change in pre-training to post-training. However, their participants did not have a CON group to compare (Ayers, 2016). It can be assumed that the reason there was not a consequential impact in this study from the HC was due to the the sample size of the participants as well as the level of subject ability. The sample size was small (N=25) providing an inadequate reading of the true effects the HC has on velocity. With more subjects, the population size would have a better reflection of the overall results and perhaps researchers would have seen significant changes in the HC effect on UW push off velocity.

Besides adding more participants to the study, a way that could have proven to be more effective and had resulted in statistical significant impact on UW push offs was if the weight training consisted of more exercises that targeted the muscle groups used in a UW push off. Plyometrics, jump training, a similar movement to a UW push off, paired with the HC could have a greater effect on velocity. Andrews et. al explored the HC and squats paired with the countermovement vertical jump on displacement and found that "the best complex training scheme was achieved by pairing countermovement jumps with hang cleans" (Andrews, 2011). Adding to this evidence, de Villarreal et al. 2011 stated that most power-training uses exercises such as jumps and the power cleans to optimize the cross-training effect. However, this study does provide evidence that can lead future researchers to search for effective pairings in exercises that will enhance swimming specific components.

In hindsight, the HC may not have been the best exercise in relative to the UW push off because it is an advanced Olympic lift that focuses on the development of power and strength. The beginning level subjects could have had different results if their swim training was paired with a cross training exercise that was more closely related to the movement of the UW push off like a vertical jump. Especially if the subjects UW push offs could benefit with technique practice over weight training, an incorporation of a dryland exercise that mimics the UW push off on land could have helped the subject understand the technique of the push off. This highlights the fact that although weight training could make a difference in sport-like movements for higher level athletes, there needs to be more studies that research the direct correlation to specific exercises related to certain swimming movements with consideration to the level of participant.

This study helped add to the literature gap by contributing to the research examining the outcome of a specific exercise on sport-like movement. The study also adds to the swimming related research that explores ways to develop a beginner swimmer's ability. More research is needed in the future to delve into the details of the HC on competitive swimming and the other physical factors (velocity, acceleration, power, etc.) of alternative sports.

Limitations:

Because this study relied on enrolled students as it's subjects, the study had to follow the class schedule put forth by the University. This also included following the schools breaks and holidays when there were no classes conducted school-wide. Four weeks into the study, the University had its annual Spring Break where there were no classes for a week. This forced both groups to take a week off in the middle of the study and pick up where they left off after the Spring Break was over. This could have caused a factor such as strength loss.

Another limitation this study faced was the fact of relying its subjects to uphold their word on not doing other outside weights. Relying on the "Honor System" is never the most efficient way to conduct research but was the only option as there was not a way to test or verify the subject's whereabouts outside of the study.

One aspect that could have hindered the study was that much of the equipment used was not gear used for the specific purpose to measure distance, time, etc. For example, a custom-built device was created to measure the distance of the UW push offs. Due to the lack of accredited measurement devices, this runs the risk of potential error.

PRACTICAL APPLICATIONS

Given the correlation that strength and conditioning cross-training has with sports, it is crucial for strength and conditioning coaches to direct their training regimes to the specific sports their athletes focus on. Swimming itself is a very unique sport that utilizes both aerobic and anaerobic capacities and works a plethora of muscle groups with the wide range of strokes and race lengths. However, there are aspects, like the underwater push off, that is utilized by every level of swimmer, race and stroke. One major factor that this study arose was taking into consideration the level of ability of the athlete. Coaches that are trying to develop the skills of beginner level athletes can utilize this study to add to the evidence showing the practicing technique will help contribute to their subjects. This study and the studies within the literature review “highlight the need for coaches to have a clear understanding of the mechanisms” that occur during each sport’s particular movements as well as adapt training to the needs and skill set of the athlete (Crowley, 2018). Strength and conditioning coaches that train competitive swimmers to novice level swimmers looking to improve can more easily find literature on that address their goals and abilities to plan the best way to help them improve their in-water performance.

ACKNOWLEDGEMENTS

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CONCLUSION

The results of the current study show the effectiveness of incorporating HC into a swimming training regime compared to swimming alone within beginner level swimmers. Subjects in both groups demonstrated no significant improvements in their UW push off velocity. Although there was significant improvement in the WT HC training, researchers found that this did not translate to the UW push off. Because of these results, it is more important to focus on the swimming technique itself for beginner level swimmers. The incorporation of weight training is necessary for more advanced level of swimmers who have experience in swimming technique. This study depicts the continual need of research on the effects weight training has on the sport of swimming. Swimmers, swim coaches and strength and conditioning coaches searching for ways to improve within the sport of swimming would benefit in exploring cross training and the different aspects it can develop as well as if it is necessary for their particular athlete's needs.

REVIEW OF LITERATURE

Overview:

Competitive swimming is a challenging Olympic sport with a wide variety of events ranging from 50-meter freestyle to the mile. When training for this range of events, swimmers utilize aerobic and anaerobic capacities which can be further developed through cross training and weight training. It is a well-known fact that the addition of weight training with sports benefit athletes in ways of increasing their strength, power, and endurance. With the sport of swimming, research shows that there are "positive associations between dry-land strength training and swimming performance" (Aspenes, 2012).

Throughout the sport of competitive swimming, when athletes primary focus are shorter races, they focus on anaerobic capacities which is defined as "the maximal rate of energy production by the combined phosphagen and anaerobic glycolytic energy systems for moderate-duration activities" and their strength as it is the primary factor that will propel them through the water (Haff, 2016). When working on their speed, athletes will work through cross training phases that start with hypertrophy, "a term to the enlargement of muscle fiber" (Haff, 2016).

Within this phase of training, there is an increase in the synthesis of the contractile proteins actin and myosin within the muscle fibers adding new myofilaments which results in muscle growth (Haff, 2016). Following this phase of strength and conditioning training is the strength phase. In this phase of training, the focuses lie on increasing weight to allow muscles to adapt to withstanding larger amounts of weight. Finally, before the resting phase which is usually incorporated before a competition, is the power phase. In the power phase of strength training, one attempts to maximize absolute peak power output by incorporate more “explosive” movements, such as jumps and weight lifting that requires more movement. In this phase, exercises target the force and velocity the athlete can produce (Haff, 2012). With the combination of all phases in an athlete’s cross training regime theoretically they will see the greatest development of aspects like strength and power in which they can incorporate into their sport performance.

On the the other hand, athletes who swim races that are further distances train more of their aerobic capacity. Their focuses lie in training their bodies to more effectively handle “repeated exposure to the acute stress of exercise” (Haff, 2012). When aerobic athletes cross train, they will focus less on the weight they are moving and more on the amount of repetitions. Within the sport of competitive swimming, a variation of muscle groups are used in regards to race and stroke focus of each individual athlete. All swimmers, no matter the length of their primary races, will work on these different phases of strength and conditioning training at one point. The difference is the amount of weight and the time spent within each phase. These phases are utilized for all strength and conditioning cross training no matter the sport.

The issue at hand is that there is not enough research verifying whether certain exercises target swimming specific events, strokes, or movements. Many strength and conditioning coaches can assume by acknowledging which exercises target certain muscle groups but when it comes to swimming specific training in relation to weight training the research is minimal. Even though it's been shown that the "mean strength can increase approximately 40% in untrained, 20% in moderately trained, and 10% in advanced participants over periods ranging from four weeks to two years", coaches can only make an educated assumption with the incorporation of a weight program their training will develop their athletes but to what extent? (Haff, 2016).

This study attempts to address a swimming specific movement done across all levels of swimming athletes (the underwater push off) and examine if by incorporating a strength and conditioning exercise that is related to the movement (hang cleans), it will improve that movement. Olympic lifting has a high-power component due to "higher movement velocities with heavy weights of the weight lifting movements" (Haff, 2012). Hang cleans is an Olympic power lift that utilizes major muscles throughout the body including "gluteus maximus, semimembranosus, semitendinosus, bicep femoris, vastus lateralis, vastus intermedius, vastus medialis, rectus femoris, soleus, gastrocnemius, deltoids, and trapezius" (Haff, 2016).

A majority of these muscle groups are used in the sport of swimming during the movement of underwater (UW) push offs therefore implying that there is an association between the hang clean exercise and underwater push off. The UW push off is a term used in the sport of swimming for when an athlete completely submerges under the surface of the water and is positioned close to the wall. On the wall, the athlete places their feet shoulder distance apart and with their hands in a streamline (one hand over the other straight over their head), they push off the wall horizontally towards the other side of the pool. This motion uses the power of jump and is similar to an on-land vertical jump. The study aims to see if athletes work the strength and conditioning movement, the hang clean, outside of the water, their UW push off in the pool will in turn increase in velocity and therefore overall swimming performance.

Throughout literary research, a few common themes related to strength and conditioning cross training for the sport of swimming and research on the effects of hang cleans arose. More specifically, these themes included the analysis of power outputs on sport-like movements and hang cleans, the power effects of jump trainings, plyometrics, the analysis of rate force development and the effects of "swimming related" cross training. As previously mentioned, the direct correlation on hang cleans and its results on swimming was slim and more specifically underwater push offs was not found. However, areas related to the two sections, hang cleans and cross training for swimming, were explored.

<u>Hang Clean Power Outputs related to Sport-Specific Movements:</u>

When looking at power output one would look at examining the results of both force and velocity. For example, a vertical jump has the athlete putting force on the ground and then it results in the velocity of the athlete leaving the ground. "Moving a heavier body at the same speed requires at a same speed [as someone moving less weight] requires a higher power output" (Haff, 2016). Producing the highest power output is essential for sport performance and sport-specific movements such as jumping, throwing, and change in direction (Haff, 2012).

Haff et al. 2012, addresses the various methods to develop power output expressing three key factors. These factors included maximizing strength because of its direct relationship to higher force development, ability to produce high forces in short periods of time and shortening the velocity. He expresses that with the development of either of these three factors, the athlete will result in having a higher power output in whichever sport related movement they are demonstrating.

Similar to Haff, Hori et al. 2008 examines the effects of the hang clean on sport-like movements (jumping, sprinting, and change in direction) in order to investigate if an athlete who performs well in hang cleans in turn have high performances in the sport specific movements. Using twenty-nine semiprofessional football players, researchers tested the players one repetition max hang clean, front squat and countermovement jump. They were then divided into two groups based off their strength which was measured by the hang cleans, squats, and jumps. The study concluded that there is a positive correlation to the ability of sport-like movements in comparison to strength. The greater the strength, the more power the athletes had. This study adds to the literature supporting the fact that by incorporating weight lifting exercises, such as hang cleans, "it may be effective to improve the athlete's capability of power" (Hori, 2008). Additionally, it addresses the possibility that the hang clean exercise could be a good indicator of an individual's strength and power.

Addressing female athletes in particular, Ayers et al. 2016 looks at the variation of different weight lifting movements and their effectiveness on improving speed, power, and strength. The study examines the hang clean and the hang snatch, two Olympic weight lifting exercises with similar physical movements, on the female athlete's vertical jumps (power), strength (back squat), and speed (40-yard dash). In the study, 23 female athletes were randomly divided into a six week hang clean and hang snatch group. As a result of the study, there were no significant difference between the two groups. However, there was improvement in the sport-like movements within both groups. Since "resistance training improves one's ability to increase force and power through both neural and morphological adaptations" it shows that with any extra cross training, an athlete should see some sort of improvement in their performance.

Similar to Ayers, Comfort et al. 2011 examined the power output effects of different variations of the Olympic hang clean weightlifting technique in regard to peak power, peak vertical ground reaction forces and rate of force development. All of which are key factors when examining power output. Using sixteen elite rugby players, researchers tried the five different variations of a power clean, hang clean being one of them, and analyzed the subject's peak power output. The hang clean, or mid-thigh power clean, resulted in having the greatest peak power. Concluding this particular variation of the power clean was the best to increase an individual's power output in regard to making the biggest difference in the subject's sport-like movements. This particular study provided further evidence for research on what the most beneficial variation of the power clean that coaches trying to improve their athlete's performance can expect the quickest and most effective results. This variation allows for "practical benefit that both are easy for less experienced athletes to learn and require less technical excellence" (Comfort, 2011).

When striving to gain the quickest results, in regard to increasing an athlete's power output, there is always a direct correlation to athlete's sport with Olympic-style weightlifting as a beneficial form of cross training. The goal is to affect someone's sport-like movement in a way that makes them faster or stronger resulting in better performance. Power output and the rate of force development has multiple times been reported to be improved through hang cleans (Helland, 2017).

<u>Power Paired with Jump Trainings:</u>

When examining a jump, we are looking at "the power produced enables the hip, knee and ankle joints to reach high angular velocities at the end of the concentric phase" (Tricoli, 2005). A jump is an essential part of many different sports including swimming. In the sport of swimming, one can witness a jump at the start of a race in the form of a dive and off the wall in an underwater push off. The jump itself, whether on land or in the water, "is widely used as a measure of lower-body power" (Watkins, 2017). Although, the majority of research looks at land-based jumping, it can be correlated to having similar effects to the horizontal jump in the water. Because training programs include strength and power increases, as examined in previously mentioned studies, the sport-like movement of a jump is an essential factor when trying to improve an athlete's performance.

Studies that directly look at the power of hang cleans and jumping find that when paired together, subjects see the most differences in their performance compared to those that do not incorporate them into their cross training. The majority of research analyzes the countermovement jump for its change in direction and the vertical jump for its distance and speed off the push (Prieske, 2018).

Andrews et. al. 2011 researched the effect of the Olympic lift of hang cleans paired with countermovement vertical jumps on vertical displacement. The study looked at common power exercises followed directly by jump training exercises. He examined 19 collegiate women athletes split up into three groups. These groups included a countermovement jump only, back squats and jumps, and hang cleans and jumps. Results concluded that athletes that were a part of the hang clean and jump group saw a greater increase in vertical displacement. This implies that when paired with a power emphasized exercise like hang cleans, the jump training will result in having the greatest distance and "[will be] superior to the back squat at maintaining consistent countermovement performance" (Andrews, 2011). This provides evidence for literature that advocates towards the development of muscular power in individuals.

Similarly, Villarreal et. al. 2011 analyzed jump performance after combining maximal power, heavy-resistance training, and plyometric (jump) training only. Using sixty-five students randomly assigned into groups for seven weeks, the countermovement jump, loaded jump, maximum rate of force development and power output were all measured. Although all groups improved, the maximum improvement was seen with the group during loaded jumps. This suggests that to obtain optimal results within individuals, an incorporation of "both traditional slow velocity training and faster power-oriented strength training alone, or in combination with plyometrics" (Villarreal, 2011).

Trocoli et al. 2005 analysed the effects of plyometric training when paired with general resistance training vs Olympic weight lifting. With the combination of heavy strength training and plyometric training improving lower body strength, it contributes to the factors of power development. In the study, thirty-two men were assigned into three groups with an increase in training volume every four weeks for a total of eight weeks. After the eight weeks, the Olympic weight lifting group seemed to produce the most improvements. Even though Olympic weightlifting might take longer to learn, "effects seem to be more beneficial for improvement in performance testing" (Trocoli, 2005).

These studies show that the combination of weight lifting on kinetic and kinematic developments on individuals lead to a greater increase in sport-related movements including jump training. As these research articles suggest, jumping, a common movement in sports, is improved through the inclusion of the component of weight lifting.

Plyometrics

Within plyometrics, also known as jump training, an "elastic energy in the musculotendinous components increased with a rapid stretch and then are stored" (Haff, 2016). A movement is followed by a concentric muscle action of stored energy immediately getting released resulting in an increased total force production. This results in the series of eccentric movements of a jump (Haff, 2016). This relatively new form of power training, works a subject's speed, explosive power, and strength. The jump, as mentioned before, is also an important movement involved in many sports. This is related to swimming through the underwater push off which consists of "jumping" off the side of the wall.

Plyometric training has been shown to improve power output and explosiveness, which can directly correlate to swimming related movements. Potdevin et al. examined a group of swimming athletes for six weeks to see if incorporating plyometric training could improve aspects of their front crawl (freestyle) swimming stroke. The subject performed jump tests including a squat jump and countermovement jump. Their freestyle tests consisted of a 50 and 400-meter swim from a dive and from a push off the wall. Potdevin was observing that there is a positive correlation between plyometric training "on swimming specific tasks such as dive or turn" which are two common examples of explosive power movements in the sport of swimming. The resulting increase in maximal velocity and acceleration during the glide on the tests allude to the relevant improvements to the performance of swimmers when plyometric cross training is incorporated to swimming training. With the hopes to add to the literature on directs cross training techniques developing the sport of swimming, Potdevin adds to the evidence advising coaches to incorporate plyometrics into their season training (Potdevin, 2011).

Plyometrics or jumping, when muscle spindles are stimulated by a rapid stretch causing a reflexed muscle action, in direct relation to swimming can improve swimmer's movements more so in the start and turn of a swim. Within these two portions of swimming, an individual is trying to maximize their velocity and improve their performance overall.

<u>Swimming Related Cross Training</u>:

Besides plyometrics enhancing swimming performance through power training, the incorporation of resistance training has been shown to improve swimming performance. Although the research in this aspect is fairly limited on its direct transfer to swimming, the studies that have been conducted address factors like the utilization of ground reaction forces on the start and turn of swimming, lower and upper body strength and injury prevention focused training.

Crowley et al. 2017 addresses via systematic review format the fact that with the limited amount of research done, the majority that is done reflects on “biokinetic swim bench, traditional weight training, and core training” his results derived from various amounts of literature and concluded that fourteen articles would be included into his systematic review based on the evidence that these fourteen articles provide resistance training interventions that show improvements in stroke rate, stroke length, or overall swimming performance. The biokinetic swim bench is used to mimic swimming movements without the use of the lower body. The studies in the systematic review indicated no improvement with the incorporation of this device into a swimming training regime. For the traditional resistance training aspect, a wide variety of exercises were examined, and the results indicated that the most effective form of resistance training for the sport of swimming was one that implemented low-volume and high-velocity resistance training exercises. In turn, swimmers will then gain a more “explosive force production transferred to swimming performance with a significant increase in velocity” (Crowley, 2017). Finally, the focus of core training showed to help stabilize and absorb forces such as muscular strength and endurance. This resulted in the athletes that had high core stability their swimming performance was higher.

Bishop et al. reviewed the weight training demands to “complement the swimmers performance” and believes the greatest difference strength and conditioning coaches can provide is to develop swimmer’s ground reaction forces. Furthermore, he addresses the importance of power and strength for swimmers and their relation to plyometrics. He emphasizes that the center of cross training for swimming should be centered around symmetry and enhancing strength and power to improve performance (Bishop, 2013).

As previously mentioned, when athletes incorporate plyometrics into their training regime, they see various improvements. Swimming is no different. When swimming training programs incorporate plyometrics into their cross training, we see an increase in maximum take-off velocity in the start and off the walls of swims (Rebutini, 2016). With the more recent found interest in plyometric training, we see studies like Rebutini et al. examining the effects of torque around the lower body joints and kinetic parameters on swimming starts once the variable of a long jump was incorporated into training. Athletes measured hip and knee extensors during isometric contraction and then performed nine weeks of jump training paired with their regular swimming training. Rebutini found that there were "significant improvements on athlete's horizontal force, impulse, and resultant force. He concluded that the long jump training was an effective way to enhance torque around the lower limbs. This study, among others, further add evidence to the effects of additional cross training improving swimming performance.

Another study conducted by Crowley et. al not only explored the weight training practice used by elite swimming strength and conditioning coaches but the rationale behind the coaches training methods. Crowley acknowledge that Olympic style weightlifting is a commonly featured cross-training method by elite swimming programs and the coaches implementing this came from a wide variety of levels, education, and backgrounds. No matter the background, one of the coaches mentioned the reasoning being including resistance training was to "increase the amount of power swimmers produce using muscle groups which are required in their main stroke" implying the importance of power throughout the sport (Crowley, 2018).

Dry-land, a broad term used in swimming, can vary anywhere from resistance training to body weight training. Dingley et al. 2015 took a group of paralympic swimmers and tested multiple forms of dry-land. This included the use of an ergometer, jump training, and weights training. Attempting to evaluate the effectiveness of dry-land, Dingley evaluated the subjects 50-

meter swim and their diving starts. Considering “a dry-land program aims at increasing the swimmer’s maximal power and thus velocity”, Dingley aimed to discover effective exercises that develop sport-specific movements in swimming. He found that there was an overall increase in the subject’s performance from before the 6-week study to after adding to evidence that by incorporating a combination of swimming and dry-land training will develop a swimmer’s performance.

Starts and off the walls in swimming are seen as the most common areas of reaching peak velocity and power in the sport. Although there are other areas, these two have been seen to be affected the most with power training like plyometrics.

<u>Rate of Force Development:</u>

When further delving into the research of power outputs, a common aspect that many researchers look at is the relationships between force and velocity in regard to time. Force is defined as the interaction of two objects. Velocity is described as both how fast and in what direction an object is traveling. The results of power training and cross training, in general, on sport performance looks at “the ability to produce force rapidly” which is arguably what the desirable traits are in athletes and what training aims to develop (Haff, 2016). In order to advance one's force, which is a common indication of strength, an athlete would theoretically work towards applying greater amounts of force during shorter periods of time in their practice. This idea is also known as the rate of force development (Haff, 2016). Typically, force development is expressed in the form of a slope determined showing “functional importance in fast and forceful muscle contractions” (Haff, 2012).

Cormie et. al. 2009 analyzes the force and velocity time curves in regard to the countermovement jump with the purpose to examine the impact of training. In his study, he looked at trained and untrained individuals. These individuals were randomly put into groups that worked on the countermovement jump training and one that did not. At the end of the study, researchers found that the time curves revealed a significant difference between the group that trained their jumping versus the non-jumping group. Similarly, the force-velocity loop, indicating total power, was also in favor of the jumpers. This shows that the training, assisted the subjects in the development of their rate of force to then produce greater power as a result. By examining a curve, coaches could more easily monitor their athlete's improvement (Cormie, 2009).

Haff et al. argues that in order to optimize the rate of force development is to incorporate both power exercises focusing on strength and an "explosive or ballistic exercise" establishing a fast increase in peak power with training. Using a combination of resistance training to enhance the high-force it "allows for a more complete adaptation to occur across the entire force-velocity curve" (Haff, 2016).

When directly looking at swimming and a force-time characteristic, Jones et. al. examined the leg-extensors in the swimming turn for swimmers at the elite level and the sub-elite level. All subjects performed a squat jump on a force platform as well as had their force measured during the turn with a force plate attached to the pool wall. As to be expected, the elite swimmers had higher strength and power characteristics. The study showed that in the push-off phase of the swimming turn, the "ability to rapidly produce force against the wall of the pool, it is clear that dryland leg extensor training helped enhance the force generating characteristics of the turn time" (Jones, 2018).

These articles portray the rate of force development through slopes that help researchers analyze the development of key aspects to sport performance like power.

Although many of these studies do not portray an exact correlation to my study, they provide multiple aspects that are all related to my study including, swimming related cross training, the effects of hang clean on sport-like movements and translating the jump on land through plyometrics related to the push off in the water.

Similar to my work, more research is needed to add to the literature on the effects of strength and conditioning training in regard to sport-like movements especially in the sport of swimming.

In regard to articles that correlated with my research, many of them included a testing period of six weeks including Prieske 2018, Potdevin 2011, Ayers 2016. The closest study related to my research would be Ayers et. al 2016 due to the fact that the researchers incorporated the same intervention (hang cleans) to measure and took another step further and used an additional testing exercise (hang snatches). Both exercises examined the effects the Olympic weight-lifting exercise on the motion of a jump.

Similarly, Oranchuk et. al. directly examined the influence of hang high pull (hang cleans) on vertical jumps. In regard to my study, instead of vertical jumps on the ground, the subjects are in the water horizontally “jumping” off the wall on an underwater push off. It is the same movement with the same variable (Oranchuk, 2019). In Oranchuk’s study, he stated the similarities between success in swimming performance as “explosive” with the greater power. Each article had aspects that related to my study and provided literature of the effects that Olympic or power related exercises have on sports performance.

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APPENDIX A: Consent Form

University of Hawai'i
Consent to Participate in a Research Project
Dr. Christopher Stickley, Principal Investigator *Katharine Santilena*,
Primary Student Investigator
Project title: The Effect of a 6-week Hang Clean Program on Underwater Push Off Velocity

Aloha! You are being asked to participate in a research study conducted by Graduate Student *Katharine Santilena* from the Kinesiology and Rehabilitation Sciences (KRS)Department at the University of Hawaii. Results will contribute to Santilena's graduate thesis.

What am I being asked to do?

If you participate in this project, you will be asked to partake in an exercise routine of hang cleans before each swimming class. At the beginning and end of the testing trial, you will be tested on your hang clean maximum weight lifted and underwater push off with video filming technology.

Taking part in this study is your choice.

This study is voluntary. You can choose to take part, or you can choose not to take part in this study. You also can change your mind at any time. If you stop being in the study, there will be no penalty or loss to you. This study will not affect your grade in the UHM KRS swimming class.

Why is this study being done?

The purpose of my project is to determine if the incorporation of the hang clean exercise into a swimming training regime will increase the velocity of underwater push offs. I am asking you to participate because as a current student enrolled in the KRS beginning swimming course, it is assumed you do not have consecutive swimming training which means your results will allow researchers to more accurately determine velocity changes within the program.

What will happen if I decide to take part in this study?

If you decide to participate in this study, you will be asked to do the following: First, you will be randomly assigned to one of two groups. Group A will consist of measurements and a swim routine. Group B will consist of measurements, a swim routine, and a weight program focused
on the hang clean exercise. These components are as follows:

1. Measurements (~30 minutes on first and last day only): Measurements will take about 30 minutes total and will be taken at the beginning and end of the study (0 and 6 weeks). The primary student investigator will lead the experimental group subjects through a supervised warm-up and a 3-repetition maximum hang clean exercise in the UH weight room located on the pool deck. Next, the trained researcher will measure the

underwater push-off velocity through a series of 5 underwater push offs recorded on an underwater camera and underwater measurement tape.

2. Hang Clean exercise routine: (~7-10 min; Group B only): This component will only be completed if subjects are randomly assigned to group B. They will complete a hang clean exercise routine 2x per week at the beginning of each swim class. The routine will be a program designed by the primary student investigator and based on the resistance training guidelines from the National Strength and Conditioning Association. We expect you to attend and participate in all sessions but if you miss a session, you will not be removed from the study.

3. Swim Routine (~40 minutes 2x/week): The swim routine is participating in the subject's regularly scheduled swim class 2 times a week within the University of Hawaii's KRS beginning swimming courses created by the class instructor (primary student investigator). Those in the control group will have an extended swimming warmup while those doing the hang clean routine complete the first 7-10 minutes of each class. Similar to the Hang Clean exercise routine, we expect you will make all of the swim sessions but if you miss a class you will not be removed from the study.

What are the risks and benefits of taking part in this study?
This study is categorized as “minimal risk”. This means there is not any risk beyond what you would experience in everyday life. However, muscle soreness may occur after hang clean program or the swim class sessions are completed. We will emphasize and remind you of ways to reduce muscle soreness such as proper stretching, hydration, and nutrition.

Potential benefits of participating in this study include increased muscular strength, participation in a supervised weight training and swim program, and improved underwater streamline development. Your participation will also contribute to a greater understanding of strategies to improve underwater push-off velocity through a hang clean weight program.

Results of Research:
You will get the results of your estimated 1RM hang clean and your push-off velocity. At the very end of the study, the PI will inform you of the overall study results upon your request.

Privacy and Confidentiality:
Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of assigning subjects with number identifiers to protect identity. Video recordings will only be seen by main researcher (Katharine Santilena) and thesis committee. The recordings will be stored in a password safe file on the main researcher’s computer which is only accessible to her.

Video recording will be done throughout the study to allow the main researcher to more accurately measure velocity underwater. Only the researcher and her committee will be able to access and view these recordings.

Other agencies that have legal permission have the right to review research records. The University of Hawaii Human Studies Program has the right to review research records for this study. When the results are reported of the research project, the use your name will not be included. Any other personal identifying information that can identify you will not be used. Instead, pseudonyms (fake names) will be used to report findings in a way that protects your
privacy and confidentiality to the extent allowed by law.

Future Research Studies:
Even after removing identifiers, the data from this study collected for this study will not be used or distributed for future research studies.

Compensation:
There will be no compensation for participation in the study.

Questions: If you have any questions about this study, please email Katharine Santilena at *kjs3@hawaii.edu*. You may also contact the researcher's advisor, *Dr. Stickley*, at *cstickle@hawaii.edu*

You may contact the UH Human Studies Program at 808.956.5007 or uhirb@hawaii.edu. to discuss problems, concerns and questions; obtain information; or offer input with an informed individual who is unaffiliated with the specific research protocol. Please visit http://go.hawaii.edu/jRd for more information on your rights as a research participant.

If you agree to participate in this project, please sign and date the following signature page and
return it to: Katharine Santilena

Keep a copy of the informed consent for your records and reference.

Signature(s) for Consent:

I give permission to join the research project entitled, The Effects of a 6 Week Hang Clean Program on Underwater Push Offs

Name of Participant (Print):

Participant's Signature:

Signature of the Person Obtaining Consent:

Date: ________________________ Mahalo!

APPENDIX B: Recruitment Email

Aloha KRS Swimmers,

We are looking for volunteers who are a part of the KRS beginning swimming classes to participate in a study! We are hoping to get at least half of your class to participate in the study.

The study consists of researching the effects of Hang Cleans strength and conditioning exercise on swimming underwater push offs. During your normal class time, subjects will be randomly split into Group A and Group B. If you are selected for Group A, you just have to participate in your regularly scheduled swim class. If you are selected for Group B, you will partake in a brief (7-10 minute) hang clean program at the start of each class for 6 weeks. During the 6-week study, following the 7-10-minute hang clean program, Group B will join the rest of the classmates to finish up the swimming class. At the beginning and end of the 6-week study, all participants (Group A and B) will be asked to have their underwater push offs video recorded to determine their velocity. For picture demonstration of a hang clean and underwater push off, see attached photos.

Again, this will not take any additional time out of your regularly scheduled class. Swimming students who do not wish to participant in the study will continue a regularly scheduled swim class.

Confidentiality for all participants will be maintained by means of assigning subjects with number identifiers to protect identity. Underwater video recordings will only be seen by main researcher (Katharine Santilena) and her thesis committee members.

Please email Katharine (Kate) Santilena by 11:59 pm February 19th at kjs3@hawaii.edu if you would like to participate or have any questions!

Mahalo!

APPENDIX C: Data Collection Forms

Hang Clean Group Records								
Subject	**Week 0: 3 RM**	**Week 1 (lb)**	**Week 2 (lb)**	**Week 3 (lb)**	**Week 4 (lb)**	**Week 5 (lb)**	**Week 6 (lb)**	**Final: 3 RM**
Sets x Reps								

Day 1 Thesis Data Collection - Underwater Push Offs										
Hang Clean Group				**Displacement**					**Velocity (m/s)**	
30.)	**Time (frames)**	3459	3509	50	**Average (frames)**	44.66666	**Average (s)**	0.3722222222	1.091820896	1.09
		6438	6482	44						
		10125	10165	40						
	Distance (inches)	23	42	19	**Average (inches)**	16	**Average (m)**	0.4064		
		30	42	12						
		23	40	17						
3.)	**Time**	48700	48740	40	**Average**	40.66666	**Average (s)**	0.3388888889	1.898754098	1.9
		43748	43790	42						
		46286	46326	40						
	Distance	28	52	24	**Average**	25.33333	**Average (m)**	0.6434666667		
		22	48	26						
		28	54	26						
33.)	**Time**	67968	68015	47	**Average**	43.33333	**Average (s)**	0.3611111111	1.359876923	1.36
		71724	71768	44						
		78193	78232	39						
	Distance	22	42	20	**Average**	19.33333	**Average (m)**	0.4910666667		
		21	41	20						
		26	44	18						
1.)	**Time**	101348	101397	49	**Average**	47.6666	**Average (s)**	0.3972222222	1.513342657	1.51
		150306	150351	45						
		156667	156716	49						
	Distance	21	42	21	**Average**	23.66666	**Average (m)**	0.6011333333		
		18	43	25						
		17	42	25						
7.)	**Time**	109068	109103	35	**Average**	37	**Average (s)**	0.3083333333	1.427891892	1.43
		164445	164484	39						
		169921	169958	37						
	Distance	23	42	19	**Average**	17.33333	**Average (m)**	0.4402666667		
		24	42	18						
		25	40	15						
13.)	**Time**	216841	216893	52	**Average**	46	**Average (s)**	0.3833333333	1.369391304	1.37
		226513	226557	44						
		228565	228607	42						
	Distance	23	43	20	**Average**	20.66666	**Average (m)**	0.5249333333		
		23	43	20						
		22	44	22						
8.)	**Time**	232930	232968	38	**Average**	35.33333	**Average (s)**	0.2944444444	1.581509434	1.58
		235311	235344	33						
		237478	237513	35						
	Distance	27	44	17	**Average**	18.33333	**Average (m)**	0.4656666667		
		27	46	19						
		26	45	19						
16.)	**Time**	242089	242125	36	**Average**	42.33333	**Average (s)**	0.3527777778	1.608	1.61
		244501	244544	43						
		246745	246793	48						

	Distance	23	48	25	**Average**	22.33333	**Average (m)**	0.5672666667		
		22	42	20						
		25	47	22						
17.)	**Time**	252061	252141	80	**Average**	46.66666	**Average (s)**	0.3888888889	1.589314286	1.59
		254343	254368	25						
		256671	256706	35						
	Distance	20	47	27	**Average**	24.33333	**Average (m)**	0.6180666667		
		24	43	19						
		20	47	27						
23.)	**Time**	6120	6155	35	**Average**	42.33333	**Average (s)**	0.3527777778	1.608	1.61
		8272	8316	44						
		11274	11322	48						
	Distance	26	46	20	**Average**	22.33333	**Average (m)**	0.5672666667		
		22	46	24						
		25	48	23						
37.)	**Time**	19165	19203	38	**Average**	38	**Average (s)**	0.3166666667	1.497263158	1.5
		21354	21391	37						
		24034	24073	39						
	Distance	27	43	16	**Average**	18.66666	**Average (m)**	0.4741333333		
		20	42	22						
		25	43	18						
20.)	**Time**	33011	33056	45	**Average**	44	**Average (s)**	0.3666666667	1.662545455	1.66
		35441	35484	43						
		50918	50962	44						
	Distance	19	44	25	**Average**	24	**Average (m)**	0.6096		
		20	42	22						
		18	43	25						
28.)	**Time**	69378	69438	60	**Average**	47	**Average (s)**	0.3916666667	1.340255319	1.34
		71639	71681	42						
		73894	73933	39						
	Distance	23	45	22	**Average**	20.66666	**Average (m)**	0.5249333333		
		27	47	20						
		23	43	20						
26.)	**Time**	81642	81679	37	**Average**	33.33333	**Average (s)**	0.2777777778	1.64592	1.65
		84192	84224	32						
		86774	86805	31						
	Distance	25	44	19	**Average**	18	**Average (m)**	0.4572		
		27	45	18						
		27	44	17						
36.)	**Time**	94254	94297	43	**Average**	42	**Average (s)**	0.35	1.596571429	1.68
		100886	100924	38						
		104969	105014	45						
	Distance	18	45	27	**Average**	22	**Average (m)**	0.5588		
		26	46	20						
		25	44	19						
Non Hang Clean Group										
2.)	**Time**	177382	177419	37	**Average**	50	**Average (s)**	0.4166666667	1.15824	1.16
		181602	181664	62						

		183974	184025	51						
	Distance	24	44	20	**Average**	19	**Average (m)**	0.4826		
		26	44	18						
		24	43	19						
34.)	**Time**	269740	269785	45	**Average**	37	**Average (s)**	0.3083333333	1.757405405	1.76
		272410	272437	27						
		274832	274871	39						
	Distance	24	46	22	**Average**	21.33333	**Average (m)**	0.5418666667		
		27	46	19						
		24	47	23						
11.)	**Time**	300011	300056	45	**Average**	45.66666	**Average (s)**	0.3805555556	1.490627737	1.49
		302076	302118	42						
		304425	304475	50						
	Distance	26	48	22	**Average**	22.33333	**Average (m)**	0.5672666667		
		26	48	22						
		24	47	23						
18.)	**Time**	314480	314531	51	**Average**	53.33333	**Average (s)**	0.4444444444	1.0287	1.03
		317813	317866	53						
		320874	320930	56						
	Distance	20	38	18	**Average**	18	**Average (m)**	0.4572		
		20	38	18						
		19	37	18						
35.)	**Time**	113973	114023	50	**Average**	48.66666	**Average (s)**	0.4055555556	1.565753425	1.57
		116503	116549	46						
		119476	119526	50						
	Distance	17	45	28	**Average**	25	**Average (m)**	0.635		
		23	46	23						
		22	46	24						
25.)	**Time**	163564	163615	51	**Average**	41.33333	**Average (s)**	0.3444444444	1.401096774	1.4
		165617	165656	39						
		167501	167535	34						
	Distance	25	46	21	**Average**	19	**Average (m)**	0.4826		
		25	45	20						
		28	44	16						
24.)	**Time**	174606	174650	44	**Average**	44.66666	**Average (s)**	0.3722222222	1.455761194	1.46
		176985	177038	53						
		181660	181697	37						
	Distance	27	47	20	**Average**	21.33333	**Average (m)**	0.5418666667		
		23	45	22						
		26	48	22						
32.)	**Time**	193293	193347	54	**Average**	44	**Average (s)**	0.3666666667	1.431636364	1.43
		196812	196849	37						
		200414	200455	41						
	Distance	20	42	22	**Average**	20.66666	**Average (m)**	0.5249333333		
		24	43	19						
		22	43	21						
15.)	**Time**	284242	284281	39	**Average**	33	**Average (s)**	0.275	1.508606061	1.51
		290275	290309	34						

		292660	292686	26						
	Distance	28	45	17	**Average**	16.33333	**Average (m)**	0.4148666667		
		28	44	16						
		28	44	16						
29.)	**Time**	149835	149867	32	**Average**	30	**Average (s)**	0.25	1.591733333	1.59
		153819	153854	35						
		157878	157901	23						
	Distance	30	48	18	**Average**	15.66666	**Average (m)**	0.3979333333		
		28	46	18						
		36	47	11						
15.)	**Time**	284242	284281	39	**Average**	33	**Average (s)**	0.275	1.508606061	1.51
		290275	290309	34						
		292660	292686	26						
	Distance	28	45	17	**Average**	16.33333	**Average (m)**	0.4148666667		
		28	44	16						
		28	44	16						

Final Day Thesis Data Collection - Underwater Push Offs										
Hang Clean Group				**Displacement**					**Velocity (m/s)**	
30.)	**Time (frames)**	26845	26892	47	**Average (frames)**	47	**Average (s)**	0.3916666667	1.313234043	1.13
		30015	30070	55						
		36559	36598	39						
	Distance (inches)	21	41	20	**Average (inches)**	20.25	**Average (m)**	0.51435		
		21	42	21						
		21	42	21						
		23	42	19						
3.)	**Time**	46648	46687	39	**Average**	36.66666	**Average (s)**	0.3055555556	1.911927273	1.91
		49413	49451	38						
		51667	51700	33						
	Distance	27	52	25	**Average**	23	**Average (m)**	0.5842		
		29	51	22						
		30	52	22						
33.)	**Time**	87257	87303	46	**Average**	49	**Average (s)**	0.4083333333	1.140408163	1.14
		93292	93337	45						
		96404	96460	56						
	Distance	24	42	18	**Average**	18.33333	**Average (m)**	0.4656666667		
		21	40	19						
		23	41	18						
1.)	**Time**	102941	102980	39	**Average**	35.33333	**Average (s)**	0.2944444444	1.926566038	1.93
		106228	106259	31						
		109268	109304	36						
	Distance	18	42	24	**Average**	22.33333	**Average (m)**	0.5672666667		
		23	44	21						
		22	44	22						
7.)	**Time**	109068	109103	35	**Average**	37	**Average (s)**	0.3083333333	1.427891892	1.43
		164445	164484	39						
		169921	169958	37						
	Distance	23	42	19	**Average**	17.33333	**Average (m)**	0.4402666667		
		24	42	18						
		25	40	15						
13.)	**Time**	234591	234633	42	**Average**	46	**Average (s)**	0.3833333333	1.258956522	1.26
		237585	237634	49						
		240705	240752	47						
	Distance	27	44	17	**Average**	19	**Average (m)**	0.4826		
		23	43	20						
		23	43	20						
8.)	**Time**	201099	201133	34	**Average**	34	**Average (s)**	0.2833333333	1.822823529	1.82
		203697	203733	36						
		206121	206153	32						
	Distance	24	43	19	**Average**	20.33333	**Average (m)**	0.5164666667		
		24	45	21						
		22	43	21						

16.)	**Time**	213865	213902	37	**Average**	43.66666	**Average (s)**	0.3638888889	1.721770992	1.72
		220722	220773	51						
		223557	223600	43						
	Distance	18	45	27	**Average**	24.66666	**Average (m)**	0.6265333333		
		22	46	24						
		23	46	23						
17.)	**Time**	181712	181761	49	**Average**	41.66666	**Average (s)**	0.3472222222	1.609344	1.61
		187102	187143	41						
		189991	190026	35						
	Distance	18	42	24	**Average**	22	**Average (m)**	0.5588		
		17	38	21						
		20	41	21						
37.)	**Time**	78036	78071	35	**Average**	33.33333	**Average (s)**	0.2777777778	1.76784	1.77
		80274	80304	30						
		82463	82498	35						
	Distance	24	41	17	**Average**	19.33333	**Average (m)**	0.4910666667		
		21	42	21						
		23	43	20						
28.)	**Time**	66526	66572	46	**Average**	42.33333	**Average (s)**	0.3527777778	1.632	1.63
		73165	73208	43						
		69787	69825	38						
	Distance	21	44	23	**Average**	22.66666	**Average (m)**	0.5757333333		
		20	43	23						
		21	43	22						
26.)	**Time**	29275	29330	55	**Average**	51	**Average (s)**	0.425	1.45427451	1.45
		32355	32405	50						
		36062	36110	48						
	Distance	21	46	25	**Average**	24.33333	**Average (m)**	0.6180666667		
		21	46	25						
		22	45	23						
36.)	**Time**	183071	183109	38	**Average**	38.33333	**Average (s)**	0.3194444444	1.722782609	1.72
		187791	187827	36						
		190362	190403	41						
	Distance	21	44	23	**Average**	21.66666	**Average (s)**	0.5503333333		
		24	46	22						
		24	44	20						
23.)	**Time**	37323	37374	51	**Average**	49.66666	**Average(m)**	0.4138888889	1.370577181	1.37
		39508	39559	51						
		44442	44489	47						
	Distance	23	47	24	**Average**	22.33333		0.5672666667		
		25	46	21						
		23	45	22						
20.)	**Time**	54348	54396	48	**Average**	44	**Average (s)**	0.3666666667	1.454727273	1.45
		56908	56956	48						
		59938	59974	36						
	Distance	22	44	22	**Average**	21	**Average (m)**	0.5334		
		24	45	21						
		24	44	20						
Non Hang Clean Group										

2.)	**Time**	5463	5516	53	**Average**	47.66666	**Average (s)**	0.3972222222	1.214937063	1.21
		8022	8066	44						
		2903	2949	46						
	Distance	26	43	17	**Average**	19	**Average (m)**	0.4826		
		24	44	20						
		23	43	20						
34.)	**Time**	124796	124836	40	**Average**	41.66666	**Average (s)**	0.3472222222	1.609344	1.61
		128256	128300	44						
		131013	131054	41						
	Distance	24	46	22	**Average**	22	**Average (m)**	0.5588		
		24	46	22						
		24	46	22						
11.)	**Time**	2747	2794	47	**Average**	48.66666	**Average (s)**	0.4055555556	1.419616438	1.42
		6634	6682	48						
		10624	10675	51						
	Distance	23	46	23	**Average**	22.66666	**Average (m)**	0.5757333333		
		24	46	22						
		23	46	23						
18.)	**Time**	140897	140948	51	**Average**	55.33333	**Average (s)**	0.4611111111	1.101686747	1.1
		145662	145725	63						
		150298	150350	52						
	Distance	17	37	20	**Average**	20	**Average (m)**	0.508		
		16	37	21						
		18	37	19						
35.)	**Time**	56460	56508	48	**Average**	44.33333	**Average (s)**	0.3694444444	1.741714286	1.74
		60642	60683	41						
		58418	58462	44						
	Distance	20	45	25	**Average**	25.33333	**Average (m)**	0.6434666667		
		21	48	27						
		22	46	24						
25.)	**Time**	40341	40390	49	**Average**	45	**Average (s)**	0.375	1.535288889	1.53
		42804	42841	37						
		45021	45070	49						
	Distance	24	47	23	**Average**	22.66666	**Average (m)**	0.5757333333		
		24	46	22						
		23	46	23						
24.)	**Time**	105749	105794	45	**Average**	43.33333	**Average (s)**	0.3611111111	1.852246154	1.85
		108337	108379	42						
		110679	110722	43						
	Distance	21	47	26	**Average**	26.33333	**Average (m)**	0.6688666667		
		21	48	27						
		22	48	26						
32.)	**Time**	73431	73475	44	**Average**	37.66666	**Average (s)**	0.3138888889	1.861168142	1.86
		76980	77010	30						
		70402	70441	39						
	Distance	19	46	27	**Average**	23	**Average (m)**	0.5842		

		25	45	20						
		23	45	22						
29.)	**Time**	91550	91602	32	**Average**	30	**Average (s)**	0.25	1.9304	1.93
		93900	93937	35						
		153365	153463	23						
	Distance	26	46	20	**Average**	19	**Average (m)**	0.4826		
		28	47	19						
		29	47	18						
15.)	**Time**	251945	251990	45	**Average**	45.33333	**Average (s)**	0.3777777778	1.232647059	1.23
		257945	257989	44						
		260990	261037	47						
	Distance	27	45	18	**Average**	18.33333	**Average (m)**	0.4656666667		
		26	44	18						
		25	44	19						